International Journal of Physics
and Research (IJPR)
ISSN(P): 2250-0030; ISSN(E): 2319-4499
Vol. 4, Issue 3, Jun 2014, 39-44

PHOTONS AS REAL PROBE OF QGP AT QUARK CHEMICAL POTENTIAL IN RELATIVISTIC HEAVY-ION COLLISIONS

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ABSTRACT

We study the photon production of leading order process from quark-gluon plasma (QGP) using various value of quark phenomenological flow parameter dependent on finite value of quark chemical potential in thermal dependent quark mass. The photon emission rate is observed in the range of low and intermediate transverse momentum. Our model results for photon measurement give the significant contribution in the range $2\gamma_g \leq \gamma_q < 6\gamma_g$ at finite value of temperature and quark chemical potential.

KEYWORDS: Photon Production, Quark-gluon Plasma (QGP), Quark Phenomenological

1. INTRODUCTION

The observations of relativistic heavy-ion collision (RHIC) provide the exact information of the quark-gluon plasma (QGP) [1–7] that is widely accepted by the experiments in RHIC at BNL and LHC at CERN. It is believe that the existence of QGP is only for a few microseconds after the big bang, so its direct detection is very difficult even in these experiments. There are many indirect signatures for detection of QGP and among all signatures; photons are considered as one of the best signal expected for a QGP [8–13]. From the emission of photons, we see the continuous emission in reaction zone, undisturbed by final-state interactions, probes the entire space-time evolution of the fireball and QCD phase transitions from confined to deconfined state of matter.

The photons are sensitive probes to the dynamics of the deconfined phase. The experimental challenge of obtaining spectra of only direct photons has been gone through by several experiments; WA98 at SPS/CERN [14] and PHENIX at RHIC/BNL [15] have showed explicit data points for direct photons. With all these information, we focus the photon radiation from the thermalized quark-gluon plasma at T = 0.25 GeV which at last freeze out to hadronic matter with the production of latent heat,that again reprocess heating and cooling into process of hadronisation as pions at around temperature T = 0.15 GeV [16].

In recent past, most of the calculations of photon production from a QGP has been done by many groups [17–20], also Bjorken's scenario assumed zero chemical potential in the plasma [21]. The assumption of QGP formation is already considered at AGS and SPS energies, however, a finite quark chemical potential has to be taken into account [22]. Even at RHIC energies, the quark chemical potential has some finite value [23]. Thus, the baryon density may be large in the QGP formation and then thermodynamic equilibrium is a function of both the temperature and the chemical potential. This would lead to the modification of photon emission rates. The significant contribution for the calculation of photon production at finite baryon density done by Ref. [24–33].

In this article, we use the a simple phenomenological model for calculating leading order process from quark-gluon plasma (QGP) using various value of quark phenomenological flow parameter dependent on finite quark chemical potential in thermal dependent quark mass. Here, quark mass is dependent on temperature and parametrization factors [34, 35]. The mass of quark shows well behaviour above critical temperature. The finite quark mass is defined as [34–38]:

$$m_q^2(T) = \gamma'_{g,q}\, g^2(p) T^2 \tag{1}$$

Where $\gamma'_{g,q}$ is the phenomenological parameter of quarks and gluons, p is the quarks (gluons) momentum, T is the temperature and g(p) is first order QCD running coupling constant taken by [37, 38]. The parameter γ'_q is taken by modifying the earlier value of γ_q. We replace γ_q by $\gamma_q\,[1 + \mu^2/\pi^2 T^2]$ [36].We represent this modified value as γ'_q and taken by [36, 39]. On the other hand, there is no change in the gluon parameter and we put it remain same as earlier one, i.e. γ'_g as γ_g. The value of γ_g is fixed as 1/3 given in the Ref. [35]. The parametrization factor $\gamma^2 = 2[1/\gamma_q^{\,2} + 1/\gamma_g^{\,2}]$. We fix the range of γ_q as $\gamma_q = 2\gamma_g$ to $8\gamma_g$ and $\gamma g = 1/3$ [35] in our calculation. The value of quark mass also removes the infrared divergence produced in photons production [40]. We compute the thermal photon emission from quark-gluon plasma of complete leading order (LO) results at temperatures T = 0.25 GeV with the arbitrary value of quark chemical potential for flavor 2.

Thus, we organize the paper as: In section § II, we show the results of LO process for photon spectra in QGP and in the section § III, we present the results and at last section § IV we give the summary.

2. THERMAL PHOTONS AT FINITE QUARK CHEMICAL POTENTIAL FROM QGP

The complete calculation of thermal photons from a partonic medium to order α_s has been done in the Ref. [17, 41–44]. We work on a finite temperature and high baryon density of QGP system after the Big-Bang process with different set of initial parameter. We extend our work of photon production by considering the LO processes for photon production.

The photon rate of momentum p is given by the expression [44, 45]

$$\frac{dN}{d^4x\, d^3p} = \frac{1}{2\pi^2} A(p)\left[\ln\left(\frac{T}{m_q(T)}\right) + \frac{1}{2}\ln\left(\frac{2E}{T}\right) + C_{tot}\left(\frac{E}{T}\right)\right] \tag{2}$$

with E = p and m_q^2 (T) is the leading order large momentum limit of the thermal quark mass. The leading-log coefficient A(p)

is given as

$$A(p) = 6\,\alpha_e \sum_f e_f^2 \frac{m_q^2(T)}{E} f_D(E) \tag{3}$$

The summation is over the number of quark flavors and e_f^2 is their electric charge, α_e is the electromagnetic constant and mass of quark is taken by Ref. [36, 37]. $f_D(E)$ is the Fermi distribution function. The dependence on the specific photon production process is written in the term C_{tot} (E/T),

$$C_{tot}\left(\frac{E}{T}\right) = C_{2\to 2}\left(\frac{E}{T}\right) + C_{brems}\left(\frac{E}{T}\right) + C_{aws}\left(\frac{E}{T}\right) \tag{4}$$

The C_{tot}(E/T) is the non-trivial function that can only be solved numerically. The results of C_{tot} (E/T) is taken by Ref. [44, 45]. Then we study the total photon spectrum above critical temperature by integrating the total rate over the space-time history of the collision. It is expressed as [45]:

$$\frac{dN}{d^2_{p_T} dy} = \int d^4x \left(E\frac{dN}{d^3pd^4x}\right) = Q\int_{\tau_0}^{\tau_f} \tau\, d\tau \int dy \left(E\frac{dN}{d^3pd^4x}\right) \tag{5}$$

With the rapidity values and $p_{T,}$ we study the total photon spectrum.

3. RESULTS

We work on calculations of photon radiation with the effect of finite temperature and quark chemical potential using phenomenological parameters such as γ_q and γ_g for flavour n_f =2. The whole set of parameters for quarks are considered after fixing the gluon parameter as the Peshier et al. value γ_g =1/3. The calculation of LO processes for photon emission is extended with the variation of phenomenological parameter value $\gamma_q = 2\gamma_g$ to 8γ_g dependent on finite value of quark chemical potential at thermal temperature T=0.25 GeV for flavour n_f = 2.We study the total photon spectrum over the space-time evolution of QGP.

In this Figure, we plot production rate of photon with transverse momentum for the various value of phenomenological parameter range $\gamma_q = 2\gamma_g$ to 8γ_g with finite value of quark chemical potential at thermal temperature T = 0.25 GeV for flavour n_f =2. We found that the photon production rate increases with increase the quark phenomenological parameter with quark chemical potential µ=0.50 GeV at fix temperature T = 0.25 GeV and there is uniform fall in total LO emission rate as a function of transverse momentum p_T for all values of phenomenological parameter that depend on quark chemical potential. The increase in the emission rate is highly effected by the temperature as well as the quark chemical potential of the system with the various set of initial condition. With $\gamma_q = 6\gamma_g$ and $\gamma_q = 8\gamma_g$ the total rate is significant large and more dominant after intermediate range of transverse momentum. At the closer inspection, we found that the photon production is insensitive for low and intermediate range of transverse momentum and give the incomplete picture of total photon spectra. So the consideration of parameterization value with $\gamma_q = 6\gamma_g$ and $\gamma_q = 8\gamma_g$ is not reliable in low and intermediate range of transverse momentum. Also we observe that the photon yield supress more as the value of parameter$\gamma_q = 4\gamma_g$. Thus, any higher values of quark phenomenological parameters are not suitably fit to get the complete pattern of photon spectra. At the same time, it is also not right to take low value of quark phenomenological parameter i.e. $\gamma_q < 2\gamma_g$ since for these values the calculation for photon rate diverges. Overall our model results are suitably valid for $\gamma_q = 2\gamma_g$ and $\gamma_q = 4\gamma_g$ with different set of parameter. We show the interesting results in the range of low and intermediate transverse momentum and found consistent output in the range $2\gamma_g \leq \gamma_q < 6\gamma_g$ to get complete picture of photon yield. Thus photons are considered as real probe of QGP at quark chemical potential in relativistic heavy-ion collisions.

4. CONCLUSIONS

The leading order production rate of photon in QGP with transverse momentum for the phenomenological parameter at $\gamma_q = 2\gamma_g$ and $4\gamma_g$ dependent on finite value of quark chemical potential at thermal temperature T=0.25 GeV for flavour n_f =2 provides a good opportunity to study the evolution of fireball in high-energy heavy-ion collisions.

The consideration of parametrization factor dependent on quark chemical potential in thermal dependent quark mass show the important role in the photon measurements. The outcome of photon production as a function of low and intermediate transverse momentum incorporating the parameterization factors with $\gamma_q = 2\gamma_g$ and $\gamma_q = 4\gamma_g$ give new improved results and also results are more enhanced as comparison to the results of Ref. [38, 45] at zero chemical potential to get complete picture. Our model results for photon measurement give the significant contribution in the range $2\gamma_g \leq \gamma_q < 6\gamma_g$ at finite value of temperature and quark chemical potential.

ACKNOWLEDGEMENTS

We thank D. S. Gosain for giving suggestions and discussions in preparing the manuscript and P. Singh is very grateful to the Department for giving him opportunities to do research here and very thankful to CSIR Fellowship for financial support.

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APPENDICES

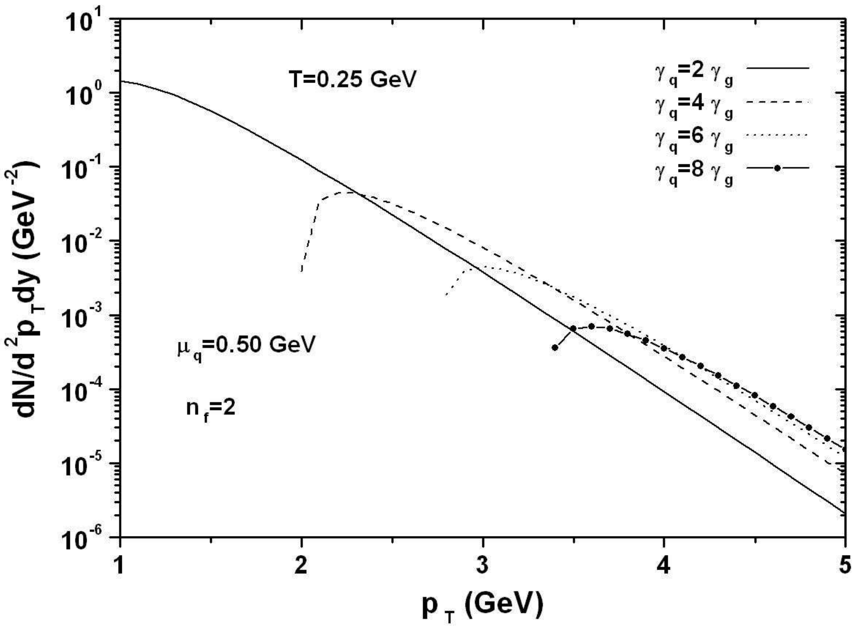

Figure 1: The Photon Spectra at Thermal Temperature T = 0.25 Gev for N_f = 2 with the Finite Value of Quark Chemical Potential M = 0.50 Gev with Fix Value of G = 1/3 and Various Value of Parameter Range from $\gamma_q' = 2[1 + \frac{\mu^2}{\pi^2 T^2}]\,\Gamma_g$ To $8[1 + \frac{\mu^2}{\pi^2 T^2}]\,\Gamma_g$ I.E. $\gamma_q = 2\gamma_g$ to $8\gamma_g$.